(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification⁷: H04B 7/185, 7/212

(21) International Application Number: PCT/US01/01772

(22) International Filing Date: 18 January 2001 (18.01.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/488,201   19 January 2000 (19.01.2000)   US

(71) Applicant: ERICSSON INC [US/US]; 7001 Development Drive, Research Triangle Park, NC 27709 (US).

(72) Inventors: KARABINIS, Peter, D.; 101 Chalon Drive, Cary, NC 27511 (US). REFAI, Wail, M.; 512 Cranborne Lane, Apex, NC 27502 (US).

(74) Agent: MYERS BIGEL SIBLEY SAJOVEC, P.A.; P.O. Box 37428, Raleigh, NC 27627 (US).

(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— with international search report
— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: DIVERSITY SYSTEM METHOD IN A SATELLITE TELECOMMUNICATION NETWORK
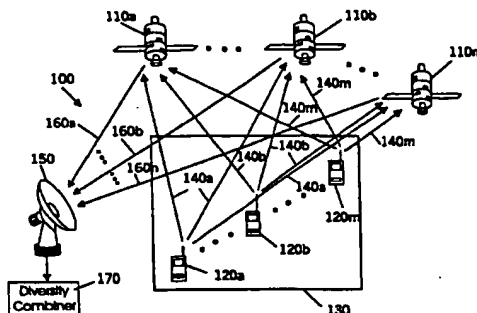
(57) Abstract: A single uplink signal burst from a user terminal in an uplink region of a satellite radiotelephone system is received during an uplink signal frame at two or more visible satellites in the uplink region. The single received signal burst from the user terminal that is received at the two or more satellites then is diversity combined. The two or more satellites preferably receive a single uplink signal burst from a plurality of, and preferably all of, the user terminals in the uplink region without time overlap, so that diversity combining may be performed. Most preferably, all of the satellites receive signal bursts from all of the user terminals in the uplink region during the uplink signal frame, without time overlap, so that return link diversity combining using all of the visible satellites may be obtained. In order to allow reception by two or more visible satellites in the return link, of signal bursts from multiple user terminals in the uplink region, a guard time is established between adjacent uplink signal bursts that are transmitted from the user terminals in the uplink region. The guard time is based upon a time of arrival difference for the adjacent uplink signal bursts to one of the satellites, for example having lowest elevation angle or at the horizon. Fixed or variable guard times may be provided between adjacent uplink signal bursts that are transmitted from user terminals in the uplink region. Thus, the satellite radiotelephone system preferably can utilize all of the transmitted signals from the user terminals, to allow improved reception by the satellite and/or reduced power consumption by the user terminals.

DIVERSITY SYSTEM METHOD IN A SATELLITE TELECOMMUNICATION NETWORK

CROSS REFERENCE TO RELATED APPLICATION

This invention is related to co-filed application Serial No. _____ to

the present inventors, entitled *Timing Systems and Methods for Forward Link*

Diversity in Satellite Radiotelephone Systems and assigned to the assignee of the

5   present invention (Attorney Docket 8194-379), the disclosure of which is hereby

incorporated herein by reference.

FIELD OF THE INVENTION

This invention relates to radiotelephone systems and methods, and more

particularly to satellite radiotelephone systems and methods.

10

BACKGROUND OF THE INVENTION

Satellite radiotelephone systems are being developed and deployed at many

locations around the world. As is known to those having skill in the art, a satellite

radiotelephone system generally includes at least one satellite and at least one

15   gateway that interfaces the satellite radiotelephone system to other telephone systems,

such as wire telephone systems and/or cellular radiotelephone systems. A plurality of

user terminals communicate with the at least one satellite, to provide satellite

communications. The user terminals may be mobile or fixed. It will be understood

that the user terminal may be a satellite radiotelephone, a combined cellular and

20   satellite radiotelephone, a high functionality terminal including Personal

Communications Systems (PCS) terminals and/or a portable computer with a satellite

radiotelephone modem. The basic principles regarding a satellite radiotelephone

system are described in the publication entitled *Dual-Mode Cellular/Satellite Hand-*

Held Phone Technology by coinventor Karabinis et al., WESCON/96, pp. 206-222,

25   October 22, 1996, and need not be described in further detail herein.

In geostationary systems, or non-geostationary systems such as Low Earth

Orbit (LEO) or Medium Earth Orbit (MEO) systems, a user terminal can

communicate with more than one satellite. Accordingly, satellite diversity may be provided so that the user terminal communicates with two satellites, to thereby allow reduced shadowing and/or blockage problems. In particular, uplink or return link signal bursts such as uplink Time Division Multiple Access (TDMA) bursts, are

5   received by at least two satellites over at least two corresponding carrier frequencies and then diversity combined, for example at a ground station that connects the satellite radiotelephone system with the wire, cellular and/or other satellite radiotelephone systems. A gain of 3dB in signal to noise ratio is obtainable when two satellites receive the same burst of equal quality and relay it to the ground station.

10   When the burst is fading in an uncorrelated fashion with respect to the two satellites, significant statistical benefits in link quality may be obtained. Improved reception of the uplink signal bursts by the satellites and/or reduced power consumption by the transmitter of the user terminals thereby may be obtained.

       Notwithstanding the above-described improvements, there continues to be a

15   desire to provide improved reception of uplink signal bursts by satellites and/or reduced power consumption by the transmitters of satellite radiotelephone system user terminals. Accordingly, there continues to be a need for improved uplink diversity systems and methods for satellite radiotelephone systems.

20   SUMMARY OF THE INVENTION

       The present invention can provide systems, methods, user terminals and satellites in which a single uplink or return link signal burst from a user terminal in an uplink region of a satellite radiotelephone system is received during an uplink signal frame at two or more visible satellites in the uplink region. The single received signal

25   burst from the user terminal that is received at the two or more visible satellites is diversity combined. The two or more satellites preferably receive a single uplink signal burst from a plurality of, and preferably all of, the user terminals in the uplink region during the uplink signal frame without time overlap, so that diversity combining can be performed. Most preferably, all of the visible satellites in the

30   uplink region receive a single uplink signal burst from each of the user terminals in the uplink region during the uplink signal frame without time overlap, so that diversity combining using all of the visible satellites in the uplink region may be obtained. Improved reception of uplink signal bursts and/or reduced power consumption in the user terminals thereby may be obtained.

In order to allow reception by two or more visible satellites in an uplink
region, of signal bursts from multiple user terminals in the uplink region, a guard time
is established between adjacent in time uplink signal bursts that are transmitted from
the user terminals in the uplink region. The guard time is based upon a time of arrival

5   difference for the adjacent uplink signal bursts to one of the visible satellites, for
example to one of the visible satellites having lowest elevation angle. Alternatively,
time of arrival differences to a real or fictitious satellite at the horizon may be used.
Fixed or variable guard times may be provided between adjacent uplink signal bursts
that are transmitted from two user terminals in the uplink region.

10   The fixed guard time preferably corresponds to a maximum time of arrival
difference between adjacent uplink signal bursts from a pair of user terminals that are
a maximum distance apart in the uplink region, to one of the plurality of satellites,
preferably to one of the plurality of satellites having lowest elevation angle or a real
or fictitious satellite at the horizon. By taking into account the maximum time of

15   arrival difference from user terminals that are a maximum distance apart in the uplink
region, it can be assured that all uplink signal bursts from all user terminals in the
uplink region will be received at two or more visible satellites, and preferably all of
the visible satellites in the uplink region, without time overlap between adjacent
bursts. Since the fixed guard time is used by all user terminals, the fixed guard time

20   can be programmed into the user terminals or otherwise provided without the need to
factor the actual position of the user terminal and/or the visible satellites. However,
the fixed guard time may be excessive for adjacent uplink signal bursts by pairs of
user terminals that are closer together than the maximum distance in the uplink
region. Accordingly, reduced complexity may be obtained at the possible expense of

25   decreased capacity.

       Variable guard times may be incorporated, according to the present invention,
between adjacent uplink signal bursts that are transmitted from the user terminals
located in the same uplink region and using the same uplink carrier frequency. The
variable guard time preferably corresponds to a time of arrival difference between

30   adjacent in time uplink signal bursts from the corresponding pair of user terminals to
one of the visible satellites, preferably the visible satellite having lowest elevation
angle or a real or fictitious satellite at the horizon. Thus, a guard time may be
computed between each pair of adjacent uplink signal bursts based on the actual
position in the uplink region of the corresponding pair of user terminals. Improved

efficiency thereby may be obtained compared to a fixed guard time, because the guard time between each pair of adjacent signal bursts may be based on the actual position of the user terminal rather than a worst case separation. Increased complexity may be produced however, because the guard time may need to be computed and separately

5   transmitted to each user terminal and may change as the position of the user terminal and/or satellite changes within the uplink region.

In the above embodiments, signal bursts from user terminals in an uplink region, and preferably signal bursts from all of the user terminals in the uplink region using the same carrier frequency, may be received at two or more, preferably all, of

10   the visible satellites in the uplink region. Thus, the satellite radiotelephone system preferably can utilize all of the transmitted signal bursts from the user terminals, to allow improved reception by the radiotelephone system and/or reduced power consumption by the user terminals.

Satellite user terminals according to the present invention include a transmitter

15   that transmits an uplink signal burst for reception by a plurality of satellites that receive transmissions from an uplink region in which the user terminal is located. The uplink signal is transmitted a guard time after an immediately preceding uplink signal burst from another user terminal in the uplink region. The guard time is based upon a time of arrival difference for the adjacent uplink signal bursts to one of the

20   plurality of visible satellites, for example having lowest elevation angle or a real or fictitious satellite at the horizon. The satellite user terminals also may include a user interface that receives user inputs including voice and/or data and provides the user inputs to the transmitter for transmission.

Satellite user terminals according to the invention may use a fixed guard time

25   that corresponds to maximum time of arrival difference between adjacent uplink signal bursts from a pair of user terminals that are a maximum distance apart in the uplink region, to one of the plurality of visible satellites, preferably the visible satellite having lowest elevation angle or a real or fictitious satellite at the horizon. Alternatively, satellite user terminals may use a variable guard time that corresponds

30   to a time of arrival difference between adjacent uplink signal bursts from the user terminal and another user terminal, to one of the plurality of visible satellites, preferably a visible satellite having lowest elevation angle or a real or fictitious satellite at the horizon.

Finally, in the above-described embodiments, the uplink or return signal bursts and downlink or forward signal bursts are communicated in a plurality of repeating uplink and downlink burst frames. Preferably, two downlink signal bursts are received from two satellites in a downlink burst frame. More preferably, the two

5   downlink signal bursts arrive at the center of the downlink region one half a downlink burst frame apart. In one embodiment, a first downlink signal burst is received from a first one of the visible satellites at a first carrier frequency, and a second downlink signal burst is received from a second one of the visible satellites at a second carrier frequency, during a single downlink signal burst frame. In another embodiment, a

10   first downlink signal burst is received from a first one of the visible satellites at a first carrier frequency, and a second downlink signal burst is received from a second one of the visible satellites at the first carrier frequency, during a single downlink signal burst frame. By providing two forward link bursts in the frame, forward link diversity also may be provided.

15

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is an overall block diagram of satellite radiotelephone systems and methods according to the present invention.

Figure 1B is a timing diagram of transmitted and received signal bursts for

20   satellite radiotelephone systems and methods of Figure 1A.

Figures 2A and 2B conceptually illustrate calculation of guard times according to the present invention.

Figure 3 is a timing diagram that illustrates integration of downlink and uplink timing according to the present invention.

25   Figures 4A and 4B are timing diagrams that illustrate alternate embodiments of forward link burst timing according to the present invention.

Figure 5 illustrates preferred embodiments of the present invention for an eighth rate GSM mode satellite radiotelephone system.

30   DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein;

rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

5   As will be appreciated by one of skill in the art, the present invention may be embodied as methods and/or devices. The present invention may take the form of an entirely hardware embodiment or an embodiment combining software and hardware aspects.

The present invention is described herein with reference to block diagrams. It will be understood that a block, and combinations of blocks, can be implemented by 10   computer program instructions. These program instructions may be provided to a processor to produce a machine, such that the instructions which execute on the processor create means for implementing the functions specified in the block or blocks. The computer program instructions may be executed by a processor to cause a series of operational steps to be performed by the processor to produce a computer 15   implemented process such that the instructions which execute on the processor provide steps for implementing the functions specified in the block or blocks.

Accordingly, blocks of the drawings support combinations of means for performing the specified functions, combinations of steps for performing the specified functions and computer program instruction means for performing the specified 20   functions. It will also be understood that each block, and combinations of blocks, can be implemented by special purpose hardware-based systems which perform the specified functions or steps, or by combinations of special purpose hardware and computer instructions.

Referring now to Figures 1A and 1B, a conceptual overview of the present 25   invention will be provided. As shown in Figure 1A, a satellite radiotelephone communications system 100, such as a LEO or MEO satellite radiotelephone communications system, includes a plurality of visible satellites 110a-110n that receive transmissions from a plurality of user terminals 120a-120m in an uplink region 130. It will be understood that although only three visible satellites 110, three 30   user terminals 120 and a single uplink region 130 is shown, a satellite radiotelephone communications system may include many more satellites, user terminals and uplink regions. The user terminals may be mobile or fixed.

As shown in Figure 1A, uplink or return link signal bursts, such as TDMA bursts, from a user terminal 120 and preferably from all of the user terminals 120a-

- 6 -

120m in the uplink region 130 are received at two or more, preferably all of the visible satellites 110a-110n in the uplink region 130. More specifically, as shown in Figure 1A, an uplink signal burst 140a from user terminal 120a is received at each of the visible satellites 110a-110n. An uplink signal burst 140b from user terminal 120b

5   is received at all of the visible satellites 110a-110n. An uplink signal burst 140m from user terminal 120m is received at all of the visible satellites 110a-110n.

The uplink signal bursts that are received at each of the visible satellites 110a-110n preferably are received without time overlap. Thus, each visible satellite 110 transmits to a ground station 150 a sequence of received uplink signal bursts without

10   time overlap. In particular, as shown in Figure 1A, satellite 110a transmits to the ground station 150 a sequence 160a of received uplink signals bursts without time overlap. Satellite 110b transmits to the ground station 150 a sequence 160b of received uplink signal bursts without time overlap. Finally, satellite 110n transmits to the ground station 150 a sequence 160n of received signal bursts without time

15   overlap. A diversity combiner 170 combines the received signals from the satellites 110a-110n. It will be understood by those having skill in the art that more than one ground station 150 may be provided, and the diversity combiner 170 need not be included in the ground station 150. Moreover, contributions from a plurality of ground stations 150 may be provided to a single diversity combiner 170.

20   In order to allow the satellites 110 to receive the uplink signal bursts without time overlap, a guard time is provided between adjacent uplink signal bursts that are transmitted from the user terminals 120. The guard time is established based upon a time of arrival difference for the adjacent uplink signal bursts to one of the satellites 110, and preferably the one of the satellites 110n having a lowest elevation angle.

25   Moreover, the guard time can be calculated assuming that the satellite with the lowest elevation angle is at the horizon. Timing diagram (1) of Figure 1B graphically illustrates a time sequence of uplink signal bursts that are transmitted by the plurality of user terminals 120a-120m with a fixed guard time G_f therebetween. The fixed guard time G_f preferably corresponds to a maximum time of arrival difference

30   between adjacent uplink signal bursts from a pair of user terminals, for example user terminals 120a and 120m, that are a maximum distance apart in the uplink region 130, to one of the satellites 110, preferably the satellite 110n having lowest elevation angle. Thus, as shown in timing diagram (4) of Figure 1B, the uplink signal bursts that are received at any of the satellites 110a-110n will be received without time

overlap. In the worst case, shown in timing diagram (3) of Figure 1B, the received

uplink signal bursts at the satellite 110n having lowest elevation angle (or at the

horizon) also will have no time overlap, although adjacent signals may abut one

another. Burst collisions therefore may be avoided.

5   Returning to timing diagram (1) of Figure 1B, since the fixed guard time G_f is

fixed for every user terminal 120, it may be preprogrammed into the user terminal or

provided to the user terminal upon initialization or at other times. Accordingly,

simplified user terminals may be obtained. However, since the worst case guard time

G_f is used regardless of the position of the user terminal, the number of user terminals

10   that may be accommodated within an uplink region may be reduced.

Timing diagram (2) of Figure 1B illustrates another embodiment of the

invention, wherein a variable guard time G_1-G_{m-1} is used that corresponds to a time of

arrival difference between adjacent uplink signal bursts from a corresponding pair of

user terminals to one of the satellites 110a-110n, preferably the satellite 110n having

15   lowest elevation angle or a real or fictitious satellite at the horizon. Again, as shown

in timing diagrams (3) and (4) of Figure 1B, two, preferably three, and most

preferably all of the satellites 110 may receive the sequence of uplink signal bursts

without time overlap. However, since the variable guard time G_1-G_{m-1} is individually

selected based on the positional relationship in the uplink region between

20   corresponding pairs of user terminals that transmit adjacent uplink signal bursts, an

increased number of signal bursts may be accommodated compared to the fixed guard

time of timing diagram (1) of Figure 1B. Unfortunately, since each user terminal

120a-120m may need to use a different guard time G_1-G_{m-1}, the guard times may need

to be computed and supplied to the individual terminals 120a-120m upon

25   initialization, and may need to change as the position of a user terminal 120 changes.

Accordingly, complexity of the user terminals and/or the satellite radiotelephone

communications system 100 may increase. It also will be understood that a system

may use both fixed and variable guard times for different user terminals 120 in the

system.

30   Figures 2A and 2B conceptually illustrate calculation of guard times according

to the present invention. Figures 2A and 2B assume that a GSM TDMA architecture

is used in a satellite radiotelephone system. In Figure 2A, it is assumed that the

uplink region 130 is 250 km by 250 km in size. Four user terminals, designated **User

#1-User #4** are shown in the uplink region 130. As shown in Figure 2A, **User #1** and

User #2 are very close to each other and a guard time need not be provided. User #2 is separated from User #3, and User #3 is separated from User #4 by a distance of about 173 km. As shown, the guard time Δt may be computed by the distance between the users Δd divided by the speed of light c (3 x 10^8m/s). In Figure 2A, the guard time between User #2 and User #3, and the guard time between User #3 and User #4 is about one forward link slot in the GSM TDMA architecture or about 0.577 msec.

Figure 2B illustrates an example where User #1 and User #2 are adjacent one another and User #3 and User #4 are adjacent one another, but User #2 and User #3 are separated by a maximum amount in an uplink region 130 of about 700 km. In this scenario, the guard time G between User #2 and User #3 is about 4 GSM forward link slots or about 2.3 msec. It also will be understood by those having skill in the art that the guard time G of Figure 2B may be used as a fixed guard time between each adjacent uplink signal burst, because it represents the worst case scenario of maximum separation between users corresponding to adjacent uplink signal bursts.

Figure 3 illustrates integration of downlink (forward) and uplink (return) timing according to the present invention. For simplicity in depicting the timing relationships, Figure 3 assumes that all user terminals are co-located within uplink region 130. As shown in timing diagrams (a) and (b) of Figure 3, first and second downlink bursts may be provided from first and second satellites at first and second carrier frequencies f1 and f2. Each burst may occupy one slot of 64 slots in an eighth rate GSM TDMA forward link frame architecture. As shown in timing diagrams (c) - (f) of Figure 3, the uplink bursts may be provided for each user using four separate frequencies and received by all satellites that are in view.

Figures 4A and 4B illustrate alternate embodiments of forward link burst timing. Figure 4A corresponds to timing diagrams (a) and (b) of Figure 3, wherein two downlink bursts are provided per frame using two separate carrier frequencies from two separate satellites. In contrast, referring to Figure 4B, one carrier frequency may be used by two satellites. In an embodiment of Figure 4B, a guard time should be provided between the last burst in the first part of the TDMA frame and the first burst in the second part of the TDMA frame. In a GSM TDMA architecture, this may reduce the capacity by about 18.75%, assuming one forward link carrier is serving a 1000 km area.

The forward link utilizes two carriers to serve each user in a diversity mode. In one embodiment, the forward link carrier frame contains 64 slots or signal bursts. This may be referred to as eighth rate GSM mode, wherein full rate GSM denotes 8 slots per frame, half rate GSM denotes 16 slots per frame, quarter rate GSM denotes 32 slots per frame and eighth rate GSM denotes 64 slots per frame.

For each forward link carrier of 200 kHz, four corresponding 50 kHz return link carriers are provided. For the eighth rate GSM embodiment, each forward link carrier can support 64 users, while each return link carrier can support 16 users.

According to a preferred embodiment, two forward link carriers are used to serve 64 users in diversity mode. Corresponding to these two forward link carriers are eight return link carriers. The return link can achieve diversity with only one transmitted burst. Figure 5 illustrates the use of eight return link carriers for each set of two forward link carriers. A guard time of one return link slot or four forward link slots, corresponding to about 2.3 msec also is shown.

The analysis of timing diagrams has revealed that as long as users who are being served by the same return link carrier, and are using adjacent in time return link slots, are within a physical distance of about 345 km, then a fixed guard time of 2.3 msec (one return link slot, or four forward link slots, or 4τ) between adjacent user bursts can suffice to preclude any burst collisions at any one of the visible satellites, including those that may be at the horizon.

Each return link carrier can support eight users subject to the maximum fixed guard time of 2.3 msec between adjacent user bursts. A single forward link region can correspond to four return link regions, i.e. a region of 1000 km x 1000 km, and can be served by two 200 kHz forward carriers, one from each of two visible satellites. Thus, 64 users can be served in diversity mode over a 1000 km x 1000 km region via two forward link carriers when the system is operating in eighth rate GSM mode, while the eight return link carriers (as shown in Figure 5) are providing return link diversity for the same 64 users.

The transmission time for each return link burst for the variable guard time case may be calculated as follows. For user 1, the transmission time may be given as follows:

$$t_T^1 = t_R^1 + 14\tau + (t_{R_c}^1 - t_R^1) \tag{1}$$

where

t_T^1 is the transmission time for user 1;

t_R^1 is the receive time for user 1;

τ is a forward link slot time; and

$t_{R_c}^1$ is the receive time for the user's downlink burst at a reference point

in the region.

Similarly, the transmit time for user 2 may be calculated as follows:

$$t_T^2 = t_R^2 + 14\tau + \frac{\Delta D_{1-2}}{c} + (t_{R_c}^2 - t_R^2), \tag{2}$$

where ΔD_{1-2} denotes the physical distance between users 1 and 2.

The transmit time for user 3 may be calculated as:

$$t_T^3 = t_R^3 + 14\tau + \frac{\Delta D_{1-2}}{c} + \frac{\Delta D_{2-3}}{c} + (t_{R_c}^3 - t_R^3), \tag{3}$$

where ΔD_{2-3} denotes the physical distance between users 2 and 3.

In general, the transmission time for any arbitrary user n corresponds to:

$$t_T^n = t_R^n + 14\tau + (\frac{1}{c} \sum_{i=2}^{n} \Delta D_{(i-1)-i}) + (t_{R_c}^n - t_R^n) \tag{4}$$

$$\text{for } n = 2,3,4,.....N; N \le 16 \tag{5}$$

$$\text{for } n = 1, t_T^1 = t_R^1 + 14\tau + (t_{R_c}^1 - t_R^1) \tag{6}$$

$$\text{Constraint}: [(t_T^N + 4\tau) - t_T^1] \le 60\tau. \tag{7}$$

where the quantity expressed by the third and fourth terms on the right hand side of

Equation (4) preferably is calculated by the Gateway and relayed to the user terminal

at call set up. The same holds for the third quantity on the right hand side of Equation

(1) and Equation (6).

For the fixed guard time case, the transmission times for each return link burst

may be calculated as:

$$t_T^n = t_R^n + 14\tau + (n-1)(4\tau) \tag{8}$$
$$n = 1,2,3,...,8$$

where each return link carrier supports eight users (assuming eighth rate GSM mode

of system operation) as is illustrated in Figure 5. It will be recognized by those

skilled in the art that $t_R^n - t_R^{n-1} = 4\tau$ for n=2, 3, ...8. This is clearly illustrated in

Figure 3.

It will be understood that the definition of N above, for example in Equation (5) and in the constraint statement of Equation (7), assumes eighth rate GSM as the mode of operation. Furthermore, it is also assumed that the forward link carrier contains 64 slot frames, whereas the return link carrier utilizes 16 slot frames, with

5   four return link carriers used to support the capacity provided by one forward link carrier. Further details on the principle of using non-symmetrical forward and return link carriers can be found in the aforementioned publication *Dual Mode Cellular Satellite Hand-Held Phone Technology* by coinventor Karabinis et al, WESCON/96, October 22, 1996, pp. 206-222. It will be understood by those skilled in the art that

10   the quantity 14τ in the above expressions is chosen as specified so that the return link pulse occurs at the terminal substantially midway between the two forward link pulses (see Figure 3). However, other values ranging from about 2τ to about 28τ may be used instead of 14τ in Equations (1), (2), (3), (4), (6) and (8). It will also be understood by those skilled in the art that the system mode of operation may be one

15   other than eighth rate GSM.

In the drawings and specification, there have been disclosed typical preferred embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

WHAT IS CLAIMED IS:

1.   A method of transmitting uplink signal bursts from a plurality of user terminals in an uplink region for reception by a plurality of visible satellites that receive transmissions from the uplink region, the method comprising the steps of:

establishing a guard time between adjacent uplink signal bursts that are
5   transmitted from two user terminals that are spaced apart from one another in the uplink region based upon a time of arrival difference for the adjacent uplink signal bursts to one of the plurality of visible satellites; and

transmitting the adjacent uplink signal bursts from the two user terminals with the guard time therebetween.

2.   A method according to Claim 1 wherein the steps of establishing and transmitting are repeatedly performed for all pairs of adjacent uplink signal bursts for the plurality of user terminals.

3.   A method according to Claim 1 wherein the one of the plurality of visible satellites corresponds to one of the plurality of visible satellites having lowest elevation angle.

4.   A method according to Claim 1 wherein the one of the plurality of visible satellites corresponds to a satellite at the horizon.

5.   A method according to Claim 1 further comprising the steps of:

receiving the adjacent signal bursts from the two user terminals at each of the plurality of visible satellites; and

diversity combining the received signals from each of the plurality of visible
5   satellites for each of the two user terminals.

6.   A method according to Claim 1 wherein the uplink signal bursts and downlink signal bursts are communicated in a plurality of repeating uplink and downlink burst frames, the method further comprising the steps of:

receiving at the user terminals, two downlink signal bursts from two of the
5   plurality of visible satellites in a downlink burst frame.

- 13 -

7.   A method according to Claim 6 wherein the receiving step comprises
the step of receiving at the user terminals, a first downlink signal burst from a first
one of the visible satellites at a first carrier frequency, and a second downlink signal
burst from a second one of the visible satellites at a second carrier frequency, during a
5   downlink signal burst frame.

· 8.   A method according to Claim 6 wherein the receiving step comprises
the step of receiving at the user terminals, a first downlink signal burst from a first
one of the visible satellites at a first carrier frequency, and a second downlink signal
burst from a second one of the visible satellites at the first carrier frequency, during a
5   downlink signal burst frame.

9.   A method of transmitting uplink signal bursts from a plurality of user
terminals in an uplink region for reception by a plurality of visible satellites that
receive transmissions from the uplink region, the method comprising the steps of:
        establishing a guard time between the uplink signal bursts that are transmitted
5   from the plurality of user terminals, the guard time corresponding to a maximum time
of arrival difference between adjacent uplink signal bursts from a pair of user
terminals that are a maximum distance apart in the uplink region to one of the
plurality of visible satellites; and
        transmitting the adjacent uplink signal bursts from the plurality of user
10   terminals with the guard time therebetween.

10.   A method according to Claim 9 wherein the step of establishing
comprises the step of establishing a guard time between the uplink signal bursts that
are transmitted from the plurality of user terminals, the guard time corresponding to a
maximum time of arrival difference between adjacent uplink signal bursts from a pair
5   of user terminals that are a maximum distance apart in the uplink region, to one of the
plurality of visible satellites having lowest elevation angle.

11.   A method according to Claim 9 wherein the step of establishing
comprises the step of establishing a guard time between the uplink signal bursts that
are transmitted from the plurality of user terminals, the guard time corresponding to a
maximum time of arrival difference between adjacent uplink signal bursts from a pair

5   of user terminals that are a maximum distance apart in the uplink region, to a satellite
    at the horizon.

    12.   A method according to Claim 9 wherein the plurality of user terminals
    comprises at least two user terminals, wherein the plurality of visible satellites
    comprises at least two visible satellites and wherein the transmitting step comprises
    the step of transmitting the adjacent uplink signal bursts from the at least two user
5   terminals to the at least two visible satellites with the guard time between all adjacent
    signal bursts.

    13.   A method according to Claim 12 further comprising the steps of:
           receiving the adjacent signal bursts from the plurality of user terminals at each
    of the plurality of visible satellites; and
5   diversity combining the received signals from each of the plurality of visible
    satellites for each of the user terminals.

    14.   A method according to Claim 12 further comprising the steps of:
           receiving the adjacent signal bursts from the at least two user terminals at each
    of the at least two visible satellites; and
           diversity combining the received signals from each of the at least two visible
5   satellites for each of the at least two user terminals.

    15.   A method according to Claim 9 wherein the uplink signal bursts and
    downlink signal bursts are communicated in a plurality of repeating uplink and
    downlink burst frames, the method further comprising the steps of:
           receiving at the user terminals, two downlink signal bursts from two of the
5   plurality of visible satellites in a downlink burst frame.

    16.   A method according to Claim 15 wherein the receiving step comprises
    the step of receiving at the user terminals, a first downlink signal burst from a first
    one of the visible satellites at a first carrier frequency, and a second downlink signal
    burst from a second one of the visible satellites at a second carrier frequency, during a
5   downlink signal burst frame.

- 15 -

17.   A method according to Claim 15 wherein the receiving step comprises the step of receiving at the user terminals, a first downlink signal burst from a first one of the visible satellites at a first carrier frequency, and a second downlink signal burst from a second one of the visible satellites at the first carrier frequency, during a

5   downlink signal burst frame.

18.   A method of transmitting uplink signal bursts from a plurality of user terminals in an uplink region for reception by a plurality of visible satellites that receive transmissions from the uplink region, the method comprising the steps of:
        establishing a variable guard time between adjacent uplink signal bursts that

5   are transmitted from the plurality of user terminals, the variable guard time corresponding to a time of arrival difference between adjacent uplink signal bursts from a corresponding pair of user terminals to one of the plurality of visible satellites; and
        transmitting the adjacent uplink signal bursts from the plurality of user

10   terminals with the variable guard times therebetween.

19.   A method according to Claim 18 wherein the step of establishing comprises the step of establishing a variable guard time between adjacent uplink signal bursts that are transmitted from the plurality of user terminals, the variable guard time corresponding to a time of arrival difference between adjacent uplink

5   signal bursts from a corresponding pair of user terminals to one of the plurality of visible satellites having lowest elevation angle.

20.   A method according to Claim 18 wherein the step of establishing comprises the step of establishing a variable guard time between adjacent uplink signal bursts that are transmitted from the plurality of user terminals, the variable guard time corresponding to a time of arrival difference between adjacent uplink

5   signal bursts from a corresponding pair of user terminals to a satellite at the horizon.

21.   A method according to Claim 18 wherein the plurality of user terminals comprises at least two user terminals, wherein the plurality of visible satellites comprises at least two visible satellites and wherein the transmitting step

- 16 -

comprises the step of transmitting the adjacent uplink signal bursts from the at least

5   two user terminals to the at least two visible satellites with the variable guard time

between all adjacent signal bursts.

22.   A method according to Claim 18 further comprising the steps of:

receiving the adjacent signal bursts from the plurality of user terminals at each

of the plurality of visible satellites; and

diversity combining the received signals from each of the plurality of visible

5   satellites for each of the user terminals.

23.   A method according to Claim 18 further comprising the steps of:

receiving the adjacent signal bursts from the at least two user terminals at each

of the at least two visible satellites; and

diversity combining the received signals from each of the at least two visible

5   satellites for each of the at least two user terminals.

24.   A method according to Claim 18 wherein the uplink signal bursts and

downlink signal bursts are communicated in a plurality of repeating uplink and

downlink burst frames, the method further comprising the steps of:

receiving at the user terminals, two downlink signal bursts from two of the

5   plurality of visible satellites in a downlink burst frame.

25.   A method according to Claim 24 wherein the receiving step comprises

the step of receiving at the user terminals, a first downlink signal burst from a first

one of the visible satellites at a first carrier frequency, and a second downlink signal

burst from a second one of the visible satellites at a second carrier frequency, during a

5   downlink signal burst frame.

26.   A method according to Claim 24 wherein the receiving step comprises

the step of receiving at the user terminals, a first downlink signal burst from a first

one of the visible satellites at a first carrier frequency, and a second downlink signal

burst from a second one of the visible satellites at the first carrier frequency, during a

5   downlink signal burst frame.

27. A method of transmitting uplink signal bursts from at least two user terminals in an uplink region for reception by at least two visible satellites that receive transmissions from the uplink region, the method comprising the step of:

transmitting a single uplink signal burst from each of the at least two user

5 terminals during a single one of a plurality of repeating uplink signal frames, with timing therebetween such that each of the at least two visible satellites receives the single uplink signal burst from each of the at least two user terminals without time overlap.

28. A method according to Claim 27 wherein the step of transmitting comprises the step of transmitting the single uplink signal burst from each of the at least two user terminals with a fixed guard time therebetween such that each of the at least two visible satellites receives the single uplink signal burst from each of the at

5 least two user terminals without time overlap.

29. A method according to Claim 27 wherein the step of transmitting comprises the step of transmitting the single uplink signal burst from each of the at least two user terminals with a variable guard time therebetween such that each of the at least two visible satellites receives the single uplink signal burst from each of the at

5 least two user terminals without time overlap.

30. A method according to Claim 27 further comprising the steps of:

receiving the adjacent signal bursts from the at least two user terminals at each of the at least two visible satellites; and

diversity combining the received signals from each of the at least two visible

5 satellites for each of the at least two user terminals.

31. A method of receiving uplink signal bursts from a plurality of user terminals in an uplink region of a satellite radiotelephone system comprising at least two visible satellites that receive transmissions from the uplink region, the method comprising the steps of:

5 receiving a single uplink signal burst from each of the user terminals at the at least two visible satellites that receive transmissions from the uplink region during a single one of a plurality of repeating uplink signal frames; and

diversity combining the single received signal burst per frame for each of the

user terminals that are received at the at least two visible satellites that receive

10   transmissions from the uplink region.

32.   A method according to Claim 31 wherein the receiving step comprises

the step of receiving a single signal burst per frame from all of the user terminals at

each of the at least two visible satellites that receive transmissions from the uplink

region without time overlap.

33.   A method of transmitting an uplink signal burst from a user terminal

for reception by a plurality of visible satellites that receive transmissions from an

uplink region in which the user terminal is located, the method comprising the step of:

       transmitting the uplink signal burst a guard time after an immediately

5   preceding uplink signal burst from another user terminal in the uplink region, the

guard time being based upon a time of arrival difference for the adjacent uplink signal

bursts to one of the plurality of visible satellites.

34.   A method according to claim 33 wherein the one of the plurality of

visible satellites corresponds to one of the plurality of visible satellites having lowest

elevation angle.

35.   A method according to Claim 33 wherein the one of the plurality of

visible satellites corresponds to a satellite at the horizon.

36.   A method according to Claim 33 further comprising the step of:

       receiving two downlink signal bursts at the user terminal from two of the

plurality of visible satellites in a downlink burst frame.

37.   A method according to Claim 36 wherein the receiving step comprises

the step of:

       receiving a first downlink signal burst from a first one of the visible satellites

at a first carrier frequency and a second downlink signal burst from a second one of

5   the visible satellites at a second carrier frequency, during the downlink signal burst

frame.

38.   A method according to Claim 36 wherein the receiving step comprises
the step of:

receiving a first downlink signal burst from a first one of the visible satellites
at a first carrier frequency and a second downlink signal burst from a second one of
5   the visible satellites at the first carrier frequency, during the downlink signal burst
frame.

39.   A method of transmitting an uplink signal burst from a user terminal
for reception by a plurality of visible satellites that receive transmissions from an
uplink region in which the user terminal is located, the method comprising the step of:
transmitting the uplink signal burst a guard time after an immediately
5   preceding uplink signal burst from another user terminal in the uplink region, the
guard time corresponding to a maximum time of arrival difference between adjacent
uplink signal bursts from a pair of user terminals that are a maximum distance part in
the uplink region, to one of the plurality of visible satellites.

40.   A method according to Claim 38 wherein the guard time corresponds
to a maximum time of arrival difference between adjacent uplink signal bursts from a
pair of user terminals that are a maximum distance part in the uplink region, to one of
the plurality of visible satellites having lowest elevation angle.

41.   A method according to Claim 39 wherein the guard time corresponds
to a maximum time of arrival difference between adjacent uplink signal bursts from a
pair of user terminals that are a maximum distance part in the uplink region, to a
satellite at the horizon.

42.   A satellite radiotelephone system receiving method comprising the step
of:

receiving uplink signal bursts from at least two user terminals in an uplink
region, at at least two visible satellites without time overlap.

43.   A method according to Claim 42 further comprising the step of:

diversity combining the received uplink signal bursts from each of the at least

two visible satellites for each of the user terminals.

44.   A satellite radiotelephone system receiving method comprising the step

of:

receiving uplink signal bursts from at least one user terminal over a single

carrier frequency at at least two visible satellites in an uplink region.

45.   A method according to Claim 44 further comprising the step of:

diversity combining the received uplink signal bursts from the at least one user

terminal.

46.   A satellite user terminal, comprising:

a transmitter that transmits an uplink signal burst for reception by a plurality

of visible satellites that receive transmissions from an uplink region in which the user

terminal is located, the uplink signal being transmitted a guard time after an

5   immediately preceding uplink signal burst from another user terminal in the uplink

region, the guard time being based upon a time of arrival difference for the adjacent

uplink signal bursts to one of the plurality of visible satellites.

47.   A user terminal according to Claim 46 wherein the one of the plurality

of visible satellites corresponds to one of the plurality of visible satellites having

lowest elevation angle.

48.   A user terminal according to claim 46 wherein the one of the plurality

of visible satellites corresponds to a satellite at the horizon.

49.   A user terminal according to Claim 46 wherein the uplink signal bursts

and downlink signal bursts are communicated in a plurality of repeating uplink and

downlink burst frames, the user terminal further comprising:

a receiver that receives two downlink signal bursts from two of the plurality of

5   visible satellites in a single downlink burst frame.

50.   A user terminal according to Claim 49 wherein the receiver receives a first downlink signal burst from a first one of the visible satellites at a first carrier frequency, and a second downlink signal burst from a second one of the visible satellites at a second carrier frequency, during the single downlink signal burst frame.

51.   A user terminal according to Claim 49 wherein the receiver receives a first downlink signal burst from a first one of the visible satellites at a first carrier frequency, and a second downlink signal burst from a second one of the visible satellites at the first carrier frequency, during a single downlink signal burst frame.

52.   A satellite user terminal, comprising:
a transmitter that transmits an uplink signal burst for reception by a plurality of visible satellites that receive transmissions from an uplink region in which the user terminal is located, the uplink signal burst being transmitted a guard time after an immediately preceding uplink signal burst from another user terminal in the uplink region, the guard time corresponding to a maximum time of arrival difference between adjacent uplink signal bursts from a pair of user terminals that are a maximum distance part in the uplink region, to one of the plurality of visible satellites.

53.   A user terminal according to Claim 52 wherein the guard time corresponds to a maximum time of arrival difference between adjacent uplink signal bursts from a pair of user terminals that are a maximum distance part in the uplink region, to one of the plurality of visible satellites having lowest elevation angle.

54.   A user terminal according to Claim 52 wherein the guard time corresponds to a maximum time of arrival difference between adjacent uplink signal bursts from a pair of user terminals that are a maximum distance apart in the uplink region to a satellite at the horizon.

55.   A satellite user terminal, comprising:
a transmitter that transmits an uplink signal burst for reception by a plurality of visible satellites that receive transmissions from an uplink region in which the user terminal is located, the uplink signal burst being transmitted a guard time after an

5   immediately preceding uplink signal burst from another user terminal in the uplink
region, the guard time corresponding to a time of arrival difference between adjacent
uplink signal bursts from the user terminal and the other user terminal, to one of the
plurality of visible satellites.

56.   A user terminal according to Claim 55 wherein the guard time
corresponds to a time of arrival difference between adjacent uplink signal bursts from
the user terminal and the other user terminal, to one of the plurality of visible satellites
having lowest elevation angle.

57.   A user terminal according to Claim 55 wherein the guard time
corresponds to a time of arrival difference between adjacent uplink signal bursts from
the user terminal and the other user terminal, to a satellite at the horizon.

58.   A satellite radiotelephone system comprising:
at least two satellites that receive uplink signal bursts from at least two user
terminals in an uplink region, each of the satellites receiving the uplink signal bursts
from the at least two user terminals without time overlap.

59.   A satellite radiotelephone system according to Claim 58 further
comprising:
a diversity combiner that combines the received uplink signal bursts from the
user terminals.

60.   A method of transmitting downlink signal bursts from a plurality of
satellites to a plurality of user terminals in a downlink region, over a plurality of
repeating downlink burst frames, the method comprising the step of:
transmitting two downlink signal bursts from two of the plurality of satellites
5   for receipt by one of the user terminals in the downlink region, such that the two
downlink signal bursts arrive at a reference point of the downlink region one half a
downlink burst frame apart.

61.   A method according to Claim 60 wherein the two downlink signal bursts are transmitted from the plurality of satellites over two respective carrier frequencies.

62.   A method according to Claim 60 wherein the two downlink signal bursts are transmitted from two of the plurality of satellites over one carrier frequency.
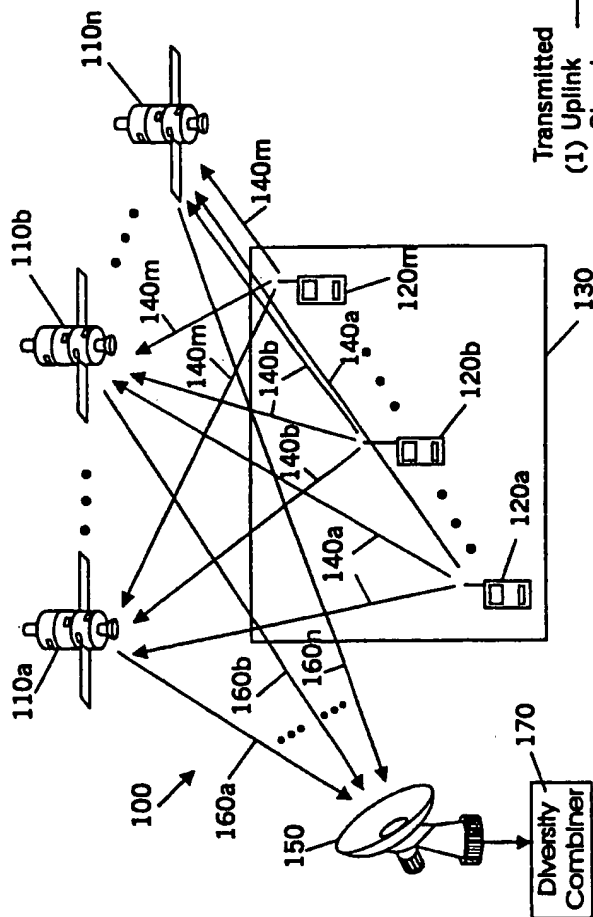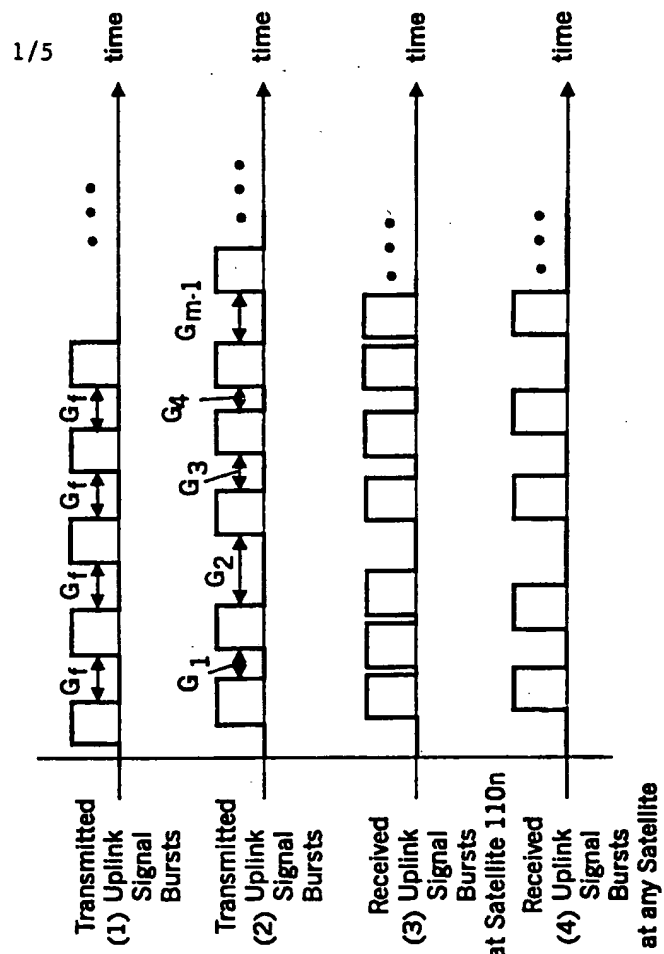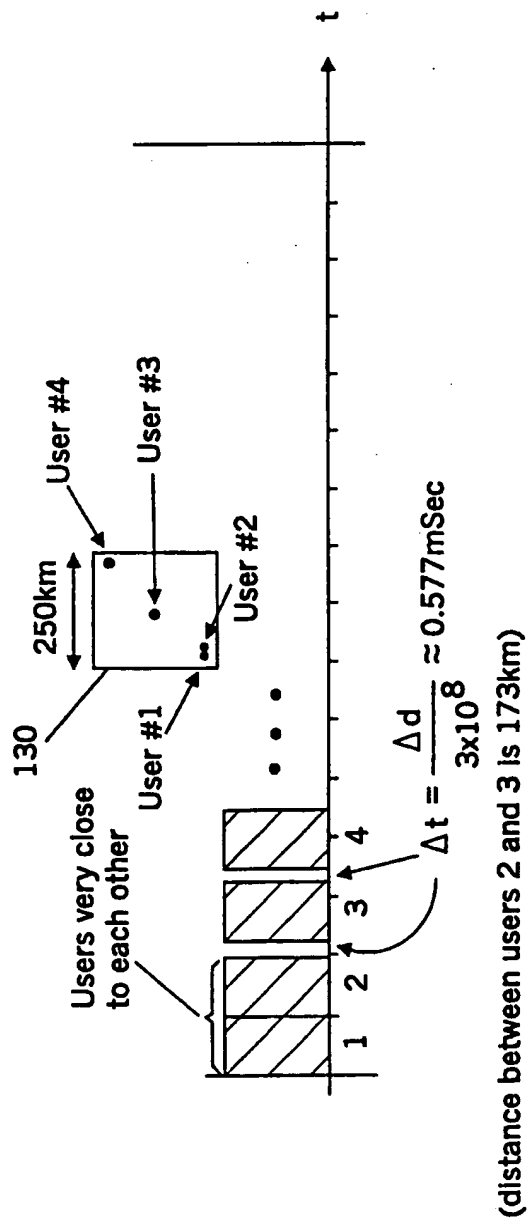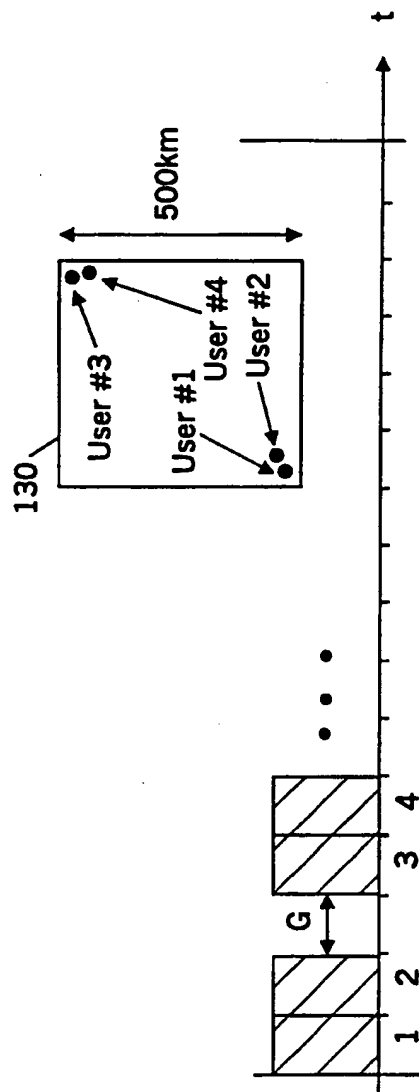
FIG. 1A

FIG. 1B

FIG. 2A
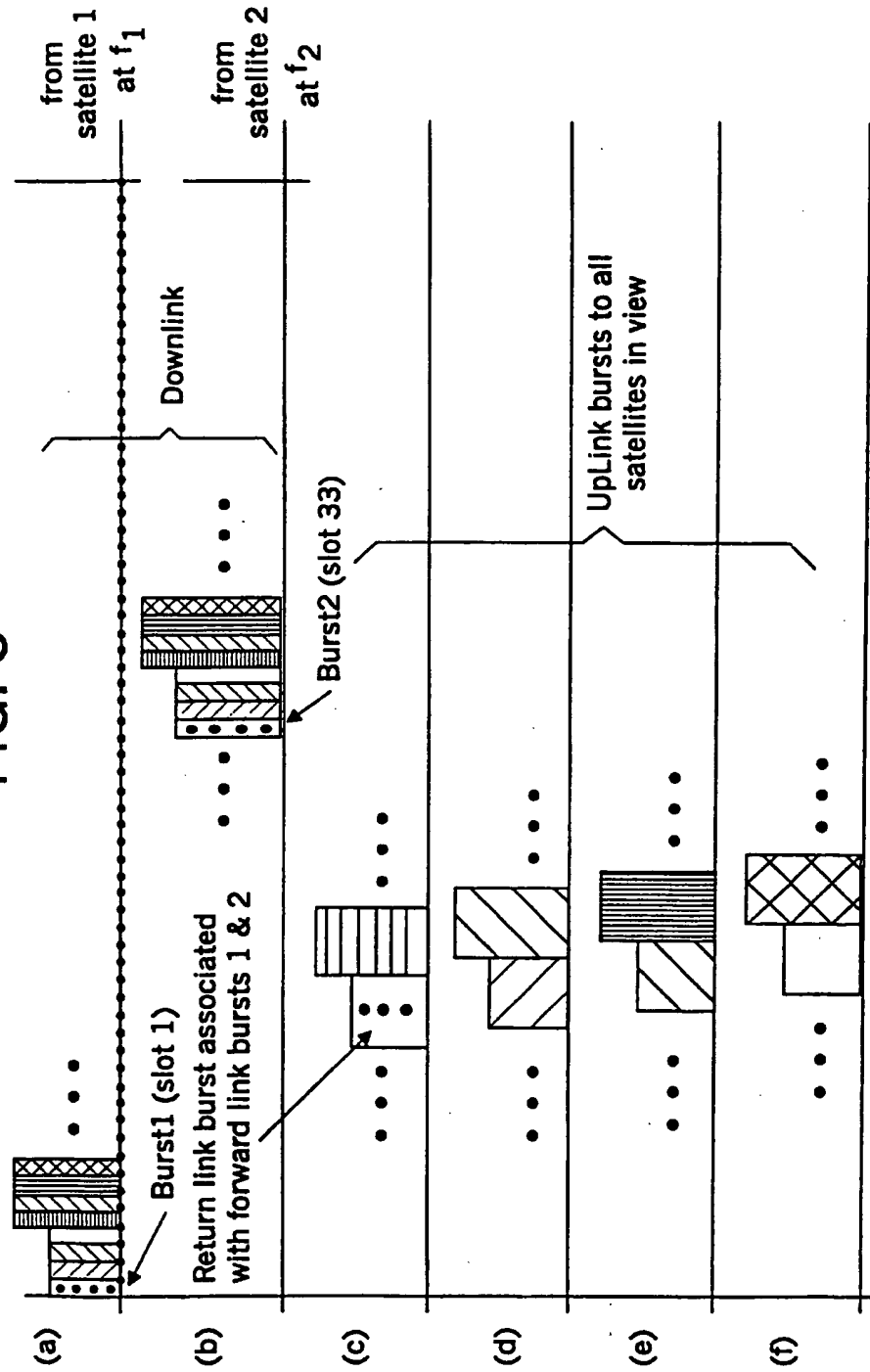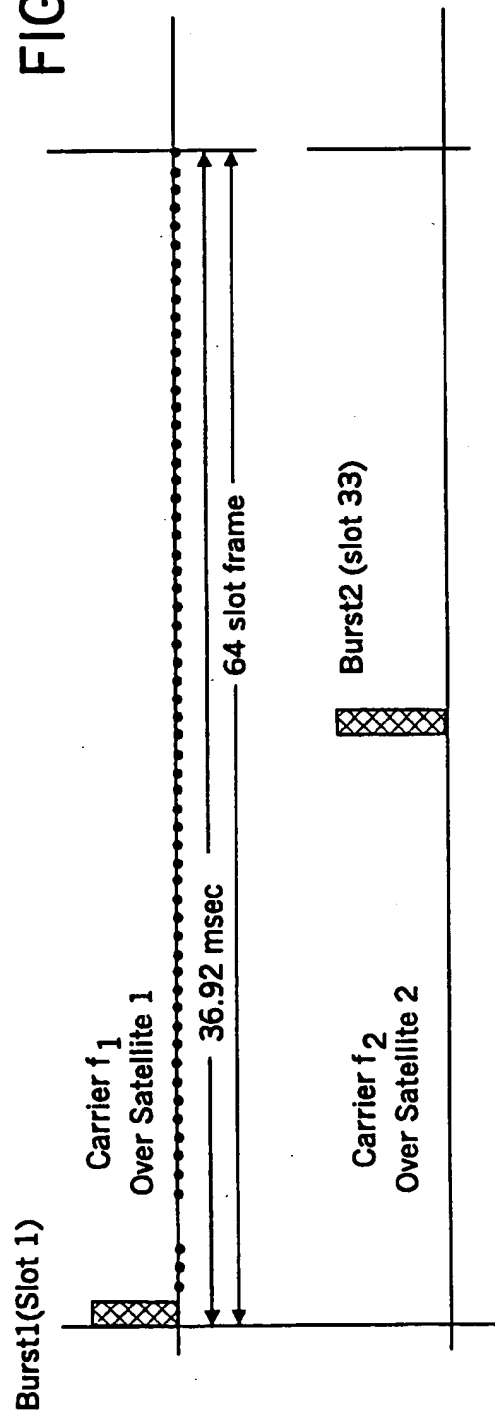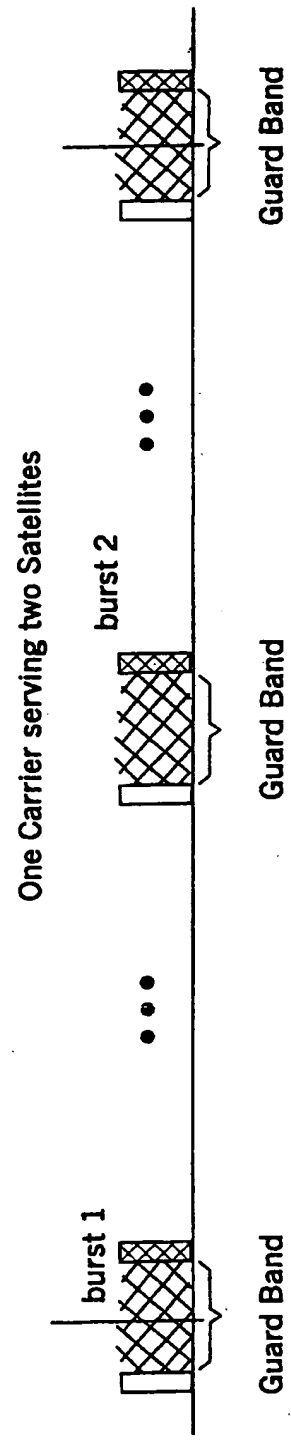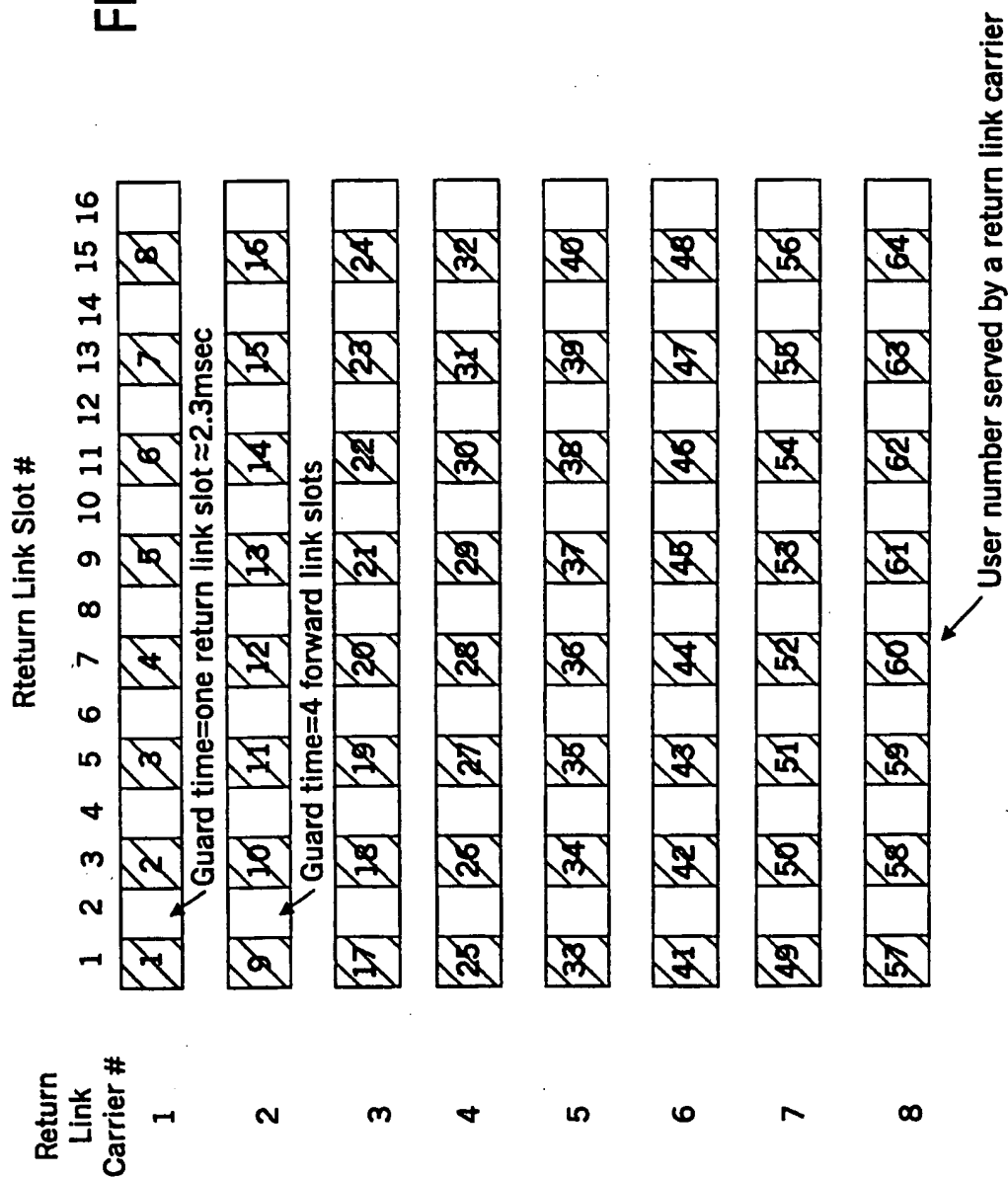
$$\Delta t = \frac{\Delta d}{3 \times 10^8} \approx 0.577 mSec$$

(distance between users 2 and 3 is 173km)

FIG. 2B

FIG. 3

FIG. 4A

Burst1(Slot 1)

Carrier f$_1$
Over Satellite 1

36.92 msec

64 slot frame

Burst2 (slot 33)

Carrier f$_2$
Over Satellite 2

FIG. 4B

One Carrier serving two Satellites

burst 1

Guard Band

Guard Band

burst 2

Guard Band

FIG. 5

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H04B7/185   H04B7/212

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 640 672 A (NAWATA HIZURU) 17 June 1997 (1997-06-17)	1,9,18, 27,33, 39,42, 44,46, 52,55, 58,60
Y	column 3, line 41 - line 65 column 6, line 38 - line 44 column 7, line 43 - line 55; figures 4,8,9 ---	5,12,13, 22,31,45
Y	WO 96 19049 A (ERICSSON GE MOBILE INC) 20 June 1996 (1996-06-20) page 11, line 21 -page 12, line 29; figure 10 ---	5,12,13, 22,31,45
	-/--	

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 May 2001	15/05/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Sorrentino, A

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 745 484 A (SCOTT LOGAN) 28 April 1998 (1998-04-28) column 16, line 20 – line 67 column 18, line 25 – line 39; figure 8A ---	1,9,18, 27,33, 39,42, 44,46, 52,55, 58,60
A	EP 0 158 327 A (NIPPON ELECTRIC CO) 16 October 1985 (1985-10-16) page 6, line 11 – line 24; claims 1-5 ---	1,9,18, 31
A	PATENT ABSTRACTS OF JAPAN vol. 013, no. 463 (E-833), 19 October 1989 (1989-10-19) & JP 01 181336 A (NEC CORP), 19 July 1989 (1989-07-19) abstract -----	1,9,18

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 5640672	A	17-06-1997	JP	2800679 B	21-09-1998
			JP	7326995 A	12-12-1995
			AU	693878 B	09-07-1998
			AU	2042395 A	07-12-1995
			DE	19520022 A	07-12-1995
			GB	2290009 A,B	06-12-1995
WO 9619049	A	20-06-1996	AU	706242 B	10-06-1999
			AU	4640896 A	03-07-1996
			CA	2207399 A	20-06-1996
			CN	1175330 A	04-03-1998
			EP	0797874 A	01-10-1997
			FI	972475 A	12-08-1997
			JP	11501468 T	02-02-1999
			US	5841766 A	24-11-1998
US 5745484	A	28-04-1998	AU	6025796 A	24-12-1996
			BR	9608548 A	06-07-1999
			CA	2223321 A	12-12-1996
			CN	1192300 A	02-09-1998
			EP	0873593 A	28-10-1998
			IL	118447 A	31-01-2000
			WO	9639749 A	12-12-1996
			US	6154486 A	28-11-2000
			US	6049538 A	11-04-2000
EP 0158327	A	16-10-1985	JP	1798005 C	12-11-1993
			JP	4080570 B	18-12-1992
			JP	60214641 A	26-10-1985
			AU	568055 B	10-12-1987
			AU	4098485 A	17-10-1985
			CA	1229437 A	17-11-1987
			DE	3583624 A	05-09-1991
			US	4599734 A	08-07-1986
JP 01181336	A	19-07-1989	JP	2776506 B	16-07-1998